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REVIEW ARTICLE



Reusing plastic waste in the production of bricks and paving blocks: a review

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ABSTRACT

The environmental concern of plastic waste (PW) generation has escalated to an alarming level due to the versatility and high demand in various applications. In order to search for an effective way to utilise PW, reusing them for the production of construction material appears as an environmentally-friendly approach. This is also because conventional construction materials often consume high energy during production has caused many environmental impacts. This review paper summarises the previous studies on reusing various PW as raw material and aggregate for construction and its properties with special attention to bricks and paving blocks. This paper begins by illustrating on the properties of plastics and the impacts of PW to the environment. Followed by discussion on reusing PW and its impacts on the overall properties of construction material. This review found that limited studies had been conducted on the usage of PW in the production of the paving block. Besides, most of the studies focused predominantly on compressive strength and water absorption as the main parameters to evaluate the characteristics of bricks and paving blocks. It is concluded that the use of PW in construction material could possibly serve as a sustainable source for construction material in the future.

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1. Introduction

Plastics are synthetic materials derived from fossil fuel used in a wide variety of forms in our everyday lives. The demand for plastics has increased tremendously due to their flexibility in the last few decades. A recent study conducted by Jambeck et al. (2018) and Agyeman et al. (2019) revealed that about 300 million tonnes of plastic waste (PW) were produced annually in the world where 8 million of them being dumped into the oceans. According to Malaysian Plastic Manufacturers Association (Malaysian Plastic Manufacturers Association (MPMA), (2018), about 2.03 million tonnes of PW was produced annually in Malaysia, which primarily produced for packaging purposes followed by the electric and electronic sectors.

The increasing generation of PW has cause many environmental problems due to its low biodegradability (Ritchie & Roser, 2018). Many initiatives are taken to reduce the accumulation of PW such as recycling and banning single-use plastic. Recycling PW was not very effective due to its labour intensive process and lower rate where only less than 10% from total PW composition was being recycled (Ferronato & Torretta, 2019).

Studies have found new methods to reuse the PW as a potential substitute to the conventional construction materials due to its robust characteristics (Yin et al., 2015). Apart from that, the addition of PW could elevate the properties of construction material such as compressive strength, water absorption rate and durability. However, there are limited studies available regarding PW in the production of construction material as bricks and paving blocks (Bolden et al., 2013; Ferreira et al., 2012; Gawande et al., 2012; Manju et al., 2017; Mansour & Ali, 2015; Tam, 2011).

The main purpose of this review article is to provide an evaluation on the recent usage of recyclable PW as both raw construction material and aggregate in the production of bricks and paving blocks. Both advantages and disadvantages of using PW as raw material and aggregate are further elucidated. Besides, the PESTLE analysis was conducted to analyse various factors correlating with reusing PW as construction material.

2. What is plastic?

Plastics are a petrochemical substance made from fossil fuel and gas used in large quantities in developed and developing countries (Gilbert, 2016; Palm & Myrin, 2018; Vaverková, 2019). Plastics can be categorised into two main types based on their response when heat is applied: namely thermoplastic and thermosets. Thermoplastics are plastics that can be melted and remolded repeatedly when heat is applied, whereas thermosets on the other hand, undergo irreversible chemical changes when heat is applied, thus cannot be reheated and remolded (Arhant & Davies, 2019; Brouwer et al., 2018; Post et al., 2020). Plastics is a versatile and robust material commonly used in numerous applications such as; packaging, construction material, clothing, household, personals care products, and transportation (d'Ambrières, 2019; Milios et al., 2018; Mrowiec, 2017; Rodrigues et al., 2019).

Laville (2019) and Palansooriya et al. (2020) stated that 40% of the demand for plastic products belonged to throwaway plastic packaging which increased from 2 million tonnes in the 1950s to 380 million tonnes in 2015. A wide range of conventional materials such as glass, steel and wood are replaced by plastics due to the prominent characteristics and generation of plastic growing steadily over the 50 years (da Costa et al., 2016; Devezas et al., 2017). Awuchi and Awuchi (2019) found that every person discards at least two pieces of PW daily. Moreover, Wang et al. (2020) and Zhou et al. (2021) reported that 400 million metric tonnes of plastic products were produced in 2018 and predicted to reach 500 million metric tonnes by 2025. About 300 billion plastic bags were produced annually where 13 million out of it ended up in the marine environment which has caused the death of 100,000 marine wildlife (Wang et al., 2020). In the European Union countries, about 50 kg of plastic was used by a person annually while 68 kg in the United States (Plastic Insight, 2014; Thiounn & Smith, 2020).

Wahab et al. (2007) found that the plastic industry in Malaysia was monopolised by polyethylene and polypropylene which is also in line with the study conducted by (MPMA). Similar thoughts shared by Khoonkari et al. (2015) also highlighted that polyethylene terephthalate (PET) is one of the polyesters widely used in the packaging industry in various forms. PET is majorly used as it has high strength due to its weight, is shatterproof and does not react with water and food. Moreover, PET is also widely available with its relatively low price in the market (Begum et al., 2020; Simsek et al., 2019).

3. Problems related to plastics

The environmental problems created by PW are evident in the increasing level of global plastic pollution in both land and ocean when thrown away aimlessly, leaving traces of dangerous chemicals (Khoonkari et al., 2015; Balakrishnan & Flora, 2017; Garcia & Robertson, 2017). PW is now widely recognised as a major contribution to environmental pollution, especially in marine and aquatic environment, resulting in a detrimental impact on wildlife (Kaiser, 2010; Wilcox et al., 2015). Rochman et al. (2013), Worm et al. (2017) and Harvey (2019) found that PW has become the center of attention since it does not break down in the natural environment and polluting the waterways. Alabi et al. (2019) and Pinto Da Costa et al. (2020) found that the PW distribution is related to the human population, where the increase of human population will directly increase the demand for plastic products leading to environmental pollution.

British Plastic Federation (2008) reported that about 4% of petrochemical feedstock is directly used in the production of plastic annually. An equal amount of fossil fuel is required to provide energy for the production of plastics. The U.S. Energy Information Administration (EIA) (2020) highlighted that most plastic products were produced using natural feedstock from crude oil refining. As a byproduct of natural gas processing, hydrocarbon gas liquids (HGLs) are produced which consist of olefins such as propylene (C_3H_6) and ethylene (C_2H_4) that are used as direct inputs in plastic manufacturing.

Sharuddin et al. (2018) and Thiounn and Smith (2020) reported more emphasis on the availability of petroleum and natural gas supply for an increasing future population than the ecological effects of dumping vast quantities of PW into the waterways. Similarly, plastic production that mainly relies on the finite source of fossil fuel will increase atmospheric carbon dioxide (CO_2) (Abdul-Latif et al., 2020; Cunningham et al., 2020; Dormer et al., 2013). According to Geyer et al. (2017), about 40% of the globally produced PW was discarded in a year and among 79% of these PW was accumulated in the landfills.

3.1. Microplastic

Based on the particle size (PW) can be divided into two (a) microplastic which is less than 5 mm in diameter and (b) macroplastic which are more than 20 mm in diameter. Various studies have reported on the inconsistent size characterisation of microplastic which prevents the direct comparison to evaluate the abundance, distribution and composition of microplastic in a various environment (Filella, 2015; Hidalgo-Ruz et al., 2012). Microplastics is identified as one of the emerging threats of plastic pollution in aquatic and marine environments (Alomar et al., 2016; Cincinelli et al., 2017; Hurley et al., 2018; Woodall et al., 2014).

Dubaish and Liebezeit (2013) highlighted that microplastics could be detected in sewage sludge and soil even after five years in the same location where it was previously discarded. Pinto Da Costa et al. (2020) and Wright and Kelly (2017) estimated that about 250 million tonnes of accumulated plastic will be ended up in the ocean by 2050 if no actions were taken. Microplastics can be are classified into primary and secondary microplastic. Primary microplastic is purposely manufactured by extrusion and grinding process to be used as raw material in other sectors such as cosmetics and microfibers from the textiles industry (Gouin et al., 2015; van Seville et al., 2015). Meanwhile, the secondary microplastics are created through mechanical, chemical or photolytic degradation of bigger pieces of plastic into fragmented pieces or fibers such as fishing nets where plastic enter into the natural environment like a marine ecosystem (Alomar et al., 2016; Andrady, 2011; Hernandez et al., 2017; Van Cauwenberghe et al., 2015).

A considerable amount of studies also found that microplastics enter into the water bodies from the municipal wastewater treatment plants (Michielssen et al., 2016). About 0 to 9000 particles of microplastics can be found per cubic meter effluent in the wastewater treatment plant (Mintenig et al., 2017). Besides, Talvitie et al. (2015) also found effluents in wastewater treatment plants have three times higher microplastic contents than the receiving water bodies despite the highly efficient wastewater treatment system. As a result, this indicated that wastewater treatment plants could be a possible source of microplastic pollution. In contrast, Carr et al. (2016) and Estahbanati and Fahrenfeld (2016) found a different connection between microplastics and wastewater treatment plants that most of the microplastics are removed in the primary treatment zones via solid and sludge settling process. The effluents are further purified in the secondary and tertiary processes. Thus, a minimum amount of microplastic will be discharged into the surface water. Following that, Ziajahromi et al. (2017) reported that about 0.21 to 1.5 microplastic particles per Litre could be found in the final wastewater effluent due to efficient treatment process.

The main difficulties circle microplastic is the monitoring process due to wide distribution, sampling and identification (Eerkes-Medrano et al., 2015; Hale, 2017; Sobek & Gustafsson, 2014). Plastics with a higher volume-to-surface area ratio increases the difficulties in monitoring processes that affect public health and the environment (Science for Environmental Policy, 2011). Microplastic could pose major biological problems to aquatic organism such as fish and mollusks, which often mistake these microplastics as food sources and such phenomena happen at all trophic levels (Van Cauwenberghe et al., 2015). Avio et al. (2015) and Li et al. (2016) reported that the marine organism's gut was predominantly filled with 1.5 to 7.6 polyethylene type of microplastic that was about 250 μm and less in size in each animal.

Apart from that, microplastics also act as a vector that carries harmful toxic compounds in the water into the marine organism's body via bio-accumulation (Ma et al., 2016). Similarly, Seuront (2018) indicated that the microplastic ingestion by microscopic organisms like zooplankton could pose adverse effects on the food chain. This will lead to health implications in the marine organisms such as blockage in the digestive tract, reduction in energy reserve disruption in the reproductive system and even alteration in deoxyribonucleic acid (DNA) level (Wright et al., 2013). Cunningham and Sigwart (2019), Shruti et al. (2019) and Bakir et al. (2014) revealed that the effect of microplastic on a particular individual, group and population of fishes is still not fully established despite the ubiquity of microplastic pollution since most of the studies focusing on quantifying the microplastic in the environment.

3.2. Impacts of plastic waste on environment

According to d'Ambrières (2019) and United Nations Environment Programme (UNEP) (2015), only 9% of the used plastic that ended up in landfills are recycled while four to 12 million metric tonnes of PW ended up in the oceans annually. Awuchi and Awuchi (2019) and Herberz et al. (2020) highlighted that most of the PW ended up in landfills are single-use plastics. Landfilling was considered as the most common and conventional method to waste management as they are affordable and require minimum attention on treatment, cleaning and separation (Torretta et al., 2016; Vaverková, 2019). However, due to limited space, landfilling has become the least preferable method and causing a major problem to the environment. Most of the PW remains at landfill sites due to improper waste management, resulting in long-term soil and underground water contamination that caused by the degradation of PW (Eriksen et al., 2014; Ihesiulor & Ugoamadi, 2011; North & Halden, 2013; Webb et al., 2012). Zmak and Hartmann (2017) and World Economic Forum Gilbert et al. (2016) estimated that the planet Earth could be covered with PW if all the waste is continuously to be sent for landfilling.

In recent years, there is growing concerned about potential environmental and public health effects related with landfills due to the types and quantities of toxic pollutants (Teuten et al., 2009; Nagy & Kuti, 2016). Alabi et al. (2019), Klemeš et al. (2020) and Pan et al. (2020) reported that PW which dumped into landfills might cause biotic and abiotic plastic degradation that eventually leach and contaminate nearby ecosystems. Besides that, gases like methane and carbon dioxide are released into the environment when decomposing the PW in landfills which contributes to the greenhouse gas emission (Alabi et al., 2019; Shen et al., 2020; Vishwakarma, 2020; Yadav et al., 2020).

Furthermore, recycling plastic could save energy as compared with producing a new material using virgin plastic. For instance, about 130 million kilo Joule (kJ) of energy are saved with one tonne of plastic being recycled. This could contribute to an annual energy saving worth 3.5 billion barrels of oil, equivalent to 176 billion USD (Hopewell et al., 2009).

On the other hand, PW incineration could result in release of carbon dioxide that cause air pollution and global warming (Chandegera et al., 2015; Cudjoe & Acquah, 2020). Even though incineration method is considered as an alternative option to landfills, however the release of toxic chemicals though this process is harmful to the environment (de Weerd et al., 2020; Hamilton et al., 2020; Hardesty et al., 2015). Harmful chemicals such as furans, dioxins, polychlorinated biphenyls (PCBs) and mercury are some of the byproducts released which is detrimental to both nature and humans (Creton, 2017; Ihesiulor & Ugoamadi, 2011; Moharir & Kumar, 2019; Singh & Sharma, 2016). Along with these chemicals, soot and ashes produced through the incineration of PW which could settle on nearby plants, soil and water bodies (Padanyi & Foldi, 2014). Moreover, these harmful chemicals might react with the water bodies causing alteration in the pH and functions of the ecosystem (Isangedighi et al., 2018; Rajmohan et al., 2019). Subsequently, rainfalls could assist these pollutants to penetrate into soil and contaminate the groundwater which eventually may bio-accumulate in the food chain (Nagy & Kuti, 2016; Wanner, 2020).

Nonetheless, incineration is also used as an alternative method to eliminate the increasing amount of PW and reduce the need for new landfill sites (Assamoi & Lawryshyn, 2012; dos Santos et al., 2020; Istrate et al., 2021). Any energy content that can be used for the generation of electricity such as fuel for blast furnaces and cement kilns as well as the processing of diesel fuel by liquefaction processes, can be recovered through the plastic incineration process (Bruvoll, 2001; Escamilla-García et al., 2020 Yang et al., 2021).

The plastics longevity in the environment is still questionable due to their non-degradable and robust properties as it has only been mass produced in the past 70 years (Vaverková, 2019; Borrelle et al., 2020).

However, these plastics might stay in the environment for decades (Andrady, 1994; Vaverková, 2019). Pocket Guide to Marine Debris (2003) reported that a plastic bottle would takes about 450 years to be fully decomposed. Meanwhile, Thompson et al. (2009b) found that there are fewer data on the accumulation of PW in the terrestrial and freshwater habitats than the marine environment. Similar thoughts shared by Bellasi et al. (2020) and Winton et al. (2020) that studies involving plastics in the freshwater systems are fewer than the marine ecosystem. Hence, this creates available knowledge gaps and causing trouble in understanding the total extend of the plastic problem.

Eriksen et al. (2014) and Ocean Crusaders (n.d.) reported that 5 trillion of plastic pieces floating on the ocean, and it takes about one year for the ocean to degrade the PW yet not entirely. Eriksen et al. (2014) also added that harmful chemicals like bisphenol A (BPA) could be released into the water during this degradation process, which is dangerous for marine organisms. Besides, the degradability of plastics depends on many factors such as temperature, oxygen level andultraviolet (UV) light exposure of the particular environment such as salt water and benthic environment (Auta et al., 2017; Weinstein et al., 2016). Moreover, the salty environment and cooling impact of the oceans could lengthen the degradation process of PW (Awuchi & Awuchi, 2019). Barnes et al. (2009) and Lelchat et al. (2020) found that the darkness and cold temperature of a benthic zone could affect the degradation rate of PW to be slower.

Besides that, when the plastics degrades, it will first break down into tiny pieces but the polymer itself might not degrade fully over time which may lead to the accumulation of plastic and result in environmental issue (Lelchat et al., 2020; Thompson et al., 2009a). At the same time, Rochman et al. (2013), Min et al. (2020) and Beltrán-Sanahuja et al. (2020) have shown sorption of chemicals such as polychlorinated biphenyls (PCB) and polybrominated diphenyls (PBDE) from the seawater in PW depends on few factors such as physico-chemical properties and type of chemicals being exposed. Rochman (2015) found that due to the continuous weathering process, the PW being altered which elevated the concentration of chemical contamination accumulated on the surface.

The International Union for Conservation of Nature (IUCN) (Union for Conservation for Nature (IUCN) 2018), reported that most of the PW found in the marine environment originated from land, such as urban and storm runoff as well as sewer overflow. Urban coastal population growth is the essential reason for the intentional or unintentional accumulation of PW in the marine environment (Vegter et al., 2014).

3.3. Impacts of plastic waste on wildlife and humans

The high number of cases where animals are affected by PW increased annually. Harvey (2019) stated that about 597 cases in 2018 where PW affecting the wildlife, mostly marine animals were reported in England and Wales that constituted to about 21% of increment as compared to 473 cases in 2015. Jambeck et al. (2018) and Tokyo Institute of Technology (2020) reported that about 700 marine species have been interacting with PW from ingestion of tiny pieces and entangled with larger pieces of PW. Tokyo Institute of Technology (2020) also added that all seven known sea turtles species are the most affected animals with the presence of PW in marine environment. PW also hinders the growth of animals and plants besides polluting the soil and ocean (Marn et al., 2020; Wang et al., 2020). Reddy (2018) reported that about 800 animal species worldwide were affected by plastic debris which is a significant type of the marine debris. In 2050, about 99% of seabird and many other species will suffered from entanglement or plastic ingestion and 17% of these species will be listed as threatened or near-threatened species (Gall & Thompson, 2015; Wilcox et al., 2015).

Rodríguez et al. (2012) and Law (2017) suggested that the prevalence of these occurrences shows the severity of PW widespread among marine environments ranging from land surface until the benthic zone. Vegter et al. (2014) claimed that despite growing awareness of this problem, it is still difficult to recognise and minimise PW impacts on the marine biota. Besides that, Eriksson et al. (2013) stated that the effects of PW generally depend on various factors such as size, accumulation and degradation rate of PW and the ecological, economical, and social value of the particular habitat. However, extra precaution must be taken to distinguish between contaminants originating from the organism and PW (Teuten et al., 2009; Lusher, 2015).

Awuchi and Awuchi (2019) and Alabi et al. (2019) found that animals are more likely to die due to PW ingestion than entanglement. Boerger et al. (2010), Choy and Drazen (2013) and Wright et al. (2013) highlighted that microplastic ingestion has been observed in almost every genus level in the Animalia

kingdom. Moreover, the susceptibility towards ingestion of PW varies according to the species (Vegter et al., 2014). Most of the animals ingested PW found in the ocean by mistaking it as a food source like jelly fish, cuttlefish and other small fishes since plastics have similar floating patterns like the other marine organisms (Hammer et al., 2012). Awuchi and Awuchi (2019) highlighted similar findings in seabirds as they have often mistaken the floating PW as their prey.

Moreover, the parent birds also unintentionally feed their nestlings with PW as food (Rodríguez et al., 2012). As a result, these animals which feed on PW will suffer from starvation, malnutrition and death as the PW damages its digestive system (Galloway, 2015). Furthermore, the ingestion of PW can lead to blockage and paralysing the gastrointestinal tract, chronic infection, and thus reduce the health level, which affect both adult and juvenile animals (Gray et al., 2012).

Besides, Gabbatiss (2018) also reported that the chemicals from plastics could cause behavioral changes in marine animals and make them vulnerable for predators' attacks. Apart from that, Rochman et al. (2014) also suggested that the chemicals leached or absorbed by the plastic such as plasticisers and heavy metals, could disrupt the growth of animal embryos. Seuront (2018) indicated that microplastic leachates have a biological effect on gastropod such as *Littorina littorea* where it decreases its vigilance and antipredator responses in *L. littorea*. Comparable thoughts were shared by Carson et al. (2011) that PW accumulation could alter the physico-chemical process in the habitat, resulting in alteration of marine wildlife species from different parts of the ocean.

Several wildlife has died by drowning or suffocating entanglement caused by fishing nets, plastic cup holders, and plastic bags (Hamlet et al., 2020). Harvey (2019) found about 3200 cases recorded in 2018 regarding damages done to wildlife due to discarded equipment like fishing nets and hooks that caused entanglement, deep wounds in the flesh and cutting off the blood supply. Richards and Beger (2011) reported that there was a decline in the habitat of shallow-water coral reefs caused by the fouling in fishing lines, abrasion and suffocation. Besides that, Barboza and Gimenez (2015) also suggested that the marine organisms have rapidly colonised the floating PW on the ocean that left for an extended time.

Moreover, PW contaminants penetrate into the pelagic and benthic zone due to its small sizes. PW absorbs and accumulate other contaminants found around the marine environment like nonylphenol, PCBs and phenanthrene (Chandegera et al., 2015). As a result, this would inevitably affect the food chain and be harmful to humans since toxic chemicals released by the PW could poison the marine organisms that are commonly used for human consumption (Erren et al., 2009; Karleskint et al., 2012).

Till present, studies on the effects of plastic on humans were narrowed and focus on specific topic only. Azoulay et al. (2019) commented that due to the insufficient information, it failed to address the importance and effects of plastic on human health at every stage of plastic life-cycle ranging from extraction to disposal. The uncertainties make informed decision-making process difficult from consumers up to the policy-makers level. Union for Conservation for Nature (IUCN) (2018) reported that invisible plastics were identified in a few samples collected from tap water and sea salt, which contain carcinogenic chemicals and could disrupt human's endocrine system. Andrews (2012) and Awuchi and Awuchi (2019) shared similar findings where the chemical additives used in plastic production is carcinogenic and may cause endocrine disruptors in humans. Meanwhile, Barboza et al. (2020) found that seafood consumers are not aware of the microplastic exposure as the impact is in a minute quantity. On the other hand, Rainieri and Barranco (2019) revealed a significant research gap that urgently required to be filled on microplastic ingestion by humans through seafood on human health.

Also, Chris and Dan (2017) and Kosuth et al. (2017) revealed that about 83% of tap water samples collected worldwide contained PW. One of the additives added in the production of plastic products is Bisphenol A (BPA) where the exposure these chemicals may cause severe biological effects such as fertility disruption (Cantonwine et al., 2013; Caporossi et al., 2020; Matuszczak et al., 2019; Ziv-Gal & Flaws, 2016). Apart from that, BPA is also said to cause damages to the gene responsible for thyroid hormone, body development and metabolism (Awuchi & Awuchi, 2019; Matuszczak et al., 2019).

4. Plastic recycling

Plastic recycling can be divided into two main process of (a) mechanical and (b) feedstock recycling. Mechanical recycling involves heating the thermoplastic waste up to its melting point and remolding the recovered polymer into pellets or directly in secondary materials. Meanwhile, feedstock recycling or commonly known as chemical recycling involves transforming the polymers by using heat or chemical agents

to yield hydrocarbon products that can be used in the production of new polymer or fuel (Assamoi & Lawryshyn, 2012; Devasahayam et al., 2019; Lee & Liew, 2020; Meys et al., 2020; Schyns & Shaver, 2021). The main objective of chemical recycling is to elevate monomer yield under shorter time and milder conditions (Coates & Getzler, 2020; Khoonkari et al., 2015; Solis & Silveira, 2020). Chemical recycling can be further accelerated by the addition of catalysts like ionic liquid, enzymes and metal salts (Abdelaal et al., 2011; Sinha et al., 2010).

Pacheco et al. (2012), Francis (2016) and Thiounn and Smith (2020) stated that there are four stages of recycling: (1) primary recycling, (2) secondary recycling, (3) tertiary recycling and (4) energy recovery. In primary recycling, PW is turned into a new product by altering any of its properties. In contrast, in secondary recycling which is also known as mechanical recycling, the PW is physically reprocessed without altering its chemical properties to produce a new product for a different purpose than the original (Briassoulis et al., 2013; Corvellec et al., 2013; de Camargo & Saron, 2020). Tertiary recycling or chemical recycling uses chemical to break down the PW into its hydrocarbon monomers through hydrolysis or pyrolysis, which can produce polymer and fuels. In energy recover, the PW is incinerated to save energy in the form of heat (Corvellec & Bramryd, 2012; Marques et al., 2018).

4.1. Difficulties faced in plastic recycling

Mourshed et al. (2017), Willis et al. (2018) and Liang et al. (2021) highlighted that the recycling and reuse rate of PW is still unsatisfactory, despite the ongoing governments' initiatives. The Environmental Protection Department (2019) of Hong Kong reported that the public awareness of plastic recycling is still weak, and declining from 2013 to 2015. Similarly, the incentives given by the government for plastics recycling technology at the end-of-life of PW is still limited (Datta & Kopczyńska 2016; Eriksen et al., 2019; Garcia & Robertson, 2017; Vollmer et al., 2020).

These phenomena might be due to (1) insufficient recycling services or recycling collection points by government and recyclers and (2) lack of adequate knowledge of the citizens (Fielding et al., 2016; Maio et al., 2013). Malaysian Plastic Manufacturers Association (MPMA) (2018) reported that the total consumption of virgin plastics in Malaysia had increased in the last few years. About 40% of these plastics are imported due to the unavailability of required grade and type in the local market. In 2015, about 34.5 metric tonnes of PW were generated among the municipal solid waste. Only 9% of it was recycled and 16% was incinerated, and 75% was left at the landfill (Thiounn & Smith, 2020). Jeswani et al. (2021) and Lazarevic et al. (2010) argued that the inefficiencies of plastic recycling could make notable environmental changes if recycled plastic is replacing virgin plastic in production.

One of the main problems in plastic recycling is the various combination of the additives such as dyes and types of plastic added during the production process to produce the desired final product (Hahladakis et al., 2018; Merrington, 2017; Nkwachukwu et al., 2013). The combination of raw materials makes the melting point and other properties of the PW to differ even within the same resin code. Thus, the whole sorting process becomes difficult to produce a new product (Eureka Recycling, n.d; d'Ambrières, 2019).

For example, plastic bottles that are usually produced through blow-molded method cannot be recycled together with tubes or trays produced through injection-molded method due to difference in the types of additives (Jambeck et al., 2015). The price for recycled plastic material varies on few factors such as colour, shape, processing method, nature of the material and the price of virgin plastic in the market (Singh et al., 2017; Sommerhuber et al., 2015; Wahab et al., 2007).

Besides, a limited potential buyer for the collected PW also contributed to being another factor for recycling to be a less preferable method. Most industrialists opt to produce a plastic product from a new non-renewable source, which is more cost-effective than recycled plastic (d'Ambrières, 2019; Khan et al., 2019). Nonetheless, the quality of plastic resin degrades when it is reheated, limiting its market value (Leal Filho et al., 2019).

Apart from that, PW collectors and recyclers often exploit the incentives and penalties system. For example, some plastic collectors recover the PW at the initial stage but did not send it to the recyclers for recycling but receive the incentives from the government and earn more by avoiding the charges related to recycling (Wang et al., 2020). The subsidies given by the government are not sufficient to cover the whole recycling process yet some recyclers who secretly disposed of the PW obtained it from the collectors (Long et al., 2019).

Another problem in plastic recycling is the cost of equipment. The efficiency rate of plastic recycling can be enhanced when the cost of the machines is more affordable (Ihesiulor & Ugoamadi, 2011; Milios et al., 2018; Zhao et al., 2018). Besides that, most of the raw materials for plastic production are imported, indirectly increasing the overall operational cost. The affluence of the recycling process depends on many factors such as cost of recycling, availability, the convenience of recycling facilities and awareness towards recycling (Carlsson, 2005; Sidique et al., 2010). d'Ambrieres, (2019) and Garcia and Robertson (2017) reported that the preparation process before plastic recycling is costly, labour intensive and require huge amount of energy. These high production cost will increase the price of the consumer's goods. When the PW is recycled and used as raw material, it will help to reduce the overall operational cost.

The plastic recycling method cannot be applied to all polymers as each type of plastic has distinct physical and chemical properties. Thermoplastics like PET are more likely to get recycled than other types of plastics due to the increasing trend of market demand (Khoonkari et al., 2015; Wang et al., 2019; Zander et al., 2018). Besides that, melting different plastics together will result in phase separation between oil and water layers. This will cause weakening of the structural strength in the final product, limiting the further application of plastic. Although the mechanical recycling method is a more preferable option, it is limited due to elaborated process and susceptibility of PW degradations (Ragaert et al., 2017; Thiounn & Smith, 2020). An alternative method to mechanical recycling is chemical or feedstock recycling. Chemical recycling allows the production of monomers or feedstock like fuels, which can be used in many fields to replace petrochemicals.

4.2. Proposed solutions in plastic recycling

Providing sufficient incentives and fundamental amenities to the PW collectors and recyclers could increase the recycling rate. Nakatani et al. (2017), Milios et al. (2020) and Wang et al. (2020) suggested that recycling of plastic involves three main key players; the collectors, recyclers and government. The main responsibility of the collectors is to collect the PW and channel it to the recyclers to use their technology to process the waste. Nevertheless, it is the government's responsibility to promote the plastic recycling industry by introducing relevant incentives and penalties. Other than that, the willingness of stakeholders to participate in the plastic recycling process would influence its effectiveness (Zaman, 2013; Nodoushani et al., 2016; Jia et al., 2019).

Besides, searching an alternative plan for regular plastics by using biodegradable plastics could be another feasible option. However, the cost of using the existing raw material to produce biodegradable plastics is more expensive than the petroleum-based plastics (Kabir et al., 2020; Oever et al., 2017).

5. Reusing plastic waste in construction sector

Over the last decade, studies on reusing PW in the construction industry as alternative material is increasing gradually. Reusing PW as a part of the construction material is considered by many researchers in recent times (Corinaldesi et al., 2015; Mir, 2015; Mohammadinia et al., 2019; Rajput & Yadav, 2016; Rokdey et al., 2015). Some studies showed PW can be added to replace the conventional material, but it is not widely used in the commercial-level application. To date, there has been little agreement on reusing PW in construction materials as it might reduce the compressive strength. However, there is evidence that PW enhances the compressive strength of the product (Awoyera & Adesina, 2020; Gu & Ozbakkaloglu, 2016; Kamaruddin et al., 2017; Sultan et al., 2020). Thus, there is a need to analyse the impacts of adding PW into the construction material in terms of the physical properties and compressive strength perspectives.

5.1. Studies on utilisation of plastic waste as construction material

A considerable amount of literature has been published on the addition of PW in construction waste such as concrete, roof tile and cement bricks. This PW is used as raw material and aggregate in the production of construction material. The mechanical properties of construction material are discussed in following sections.

5.1.1. Density

Density of construction material varies according to the amount and types of materials used. Previous studies mostly used polyethylene (PE) in the production of construction material due to its recyclable properties and availability in abundance. Saikia and de Brito (2014) found that the density of concrete decreases as the amount of PET aggregate increases from 5, 10 to 15%. This is probably due to the light weight nature and round shape of PET aggregate that resulted in poor bonding. Similar findings were also recorded by Hameed and Ahmed (2019), where the density of light weight concrete decreased to 2.15 g/cm³ when 10% PET bottles were used as the alternative aggregate.

Besides PE, other types of plastics such as polyvinyl chloride (PVC), polypropylene (PP) and polystyrene also used in the production of construction materials. Kathe et al. (2015) studied using PE, PVC and PP as fine aggregate to replace fine sand in light weight concrete. This study proved that besides PW, aluminum powder additives could also be added to minimise the density. In another study, Akinyele and Toriola (2018) used crushed PP in 5, 10, 15, 20 and 100% to produce concrete as fine aggregate. The density of concrete is reduced as the amount of PP increases. These previous studies highlighted that the addition of PW could reduce the density, produce light-weighted construction material especially concrete in comparison with the conventional construction material. Besides that, it is also found that PW added as an alternative fine aggregate to replace sand to prevent sand exploitation. Besides that, PW also added in the production of self-consolidating concrete (SCC). Ghanem et al. (2021) utilised PP fibers in SCC found the density of PP unreinforced concrete is higher compared to PP reinforced concrete.

5.1.2. Compressive strength

Compressive strength is a widely considered parameter for any construction material. Saxena et al. (2018) utilised PET as fine and coarse aggregate in concrete. The results showed that the size of PW aggregate does play a role in compressive strength as concrete with fine aggregate have lower strength of 5.4 N/mm² as compared with coarse aggregate concrete (6.9 N/mm²). Meanwhile, Saikia and de Brito (2014) used PET as aggregate in various size and shapes; pellet-shaped (PP), coarse particle (PC) and fine particle (PF) in concrete. The findings suggested that the round shape of PP help the PW to mix well with cement paste and achieved the highest compressive strength. The sharp edges of PC and PF resulted in poor bonding and reduced compressive strength.

Hameed & Ahmed (2019) also used PET as aggregate in lightweight concrete production. Similarly, the compressive strength decreases as the amount of PET increases and the highest compressive strength (20.72 N/mm²) was recorded when 1% of PET was used. In a similar application, Kathe et al. (2015) utilised PVC, PP and PE found that the compressive strength decreases as the amount of PW increases. A similar trend was also observed in Rai et al. (2012) where an increasing amount of PW decreases the compressive strength. In another study by Panyakapo and Panyakapo (2008) melamine was used to produce lightweight concrete. The results showed that a high proportion of melamine decreases the compressive strength of concrete.

These studies showed that replacing PW as aggregate in the production of concrete decreases the compressive strength. This is mainly due to the bond between plastic and cement paste weaken by absorbing a high amount of water. Apart from that, the poor adhesion property of PW with cement plastic reduces the strength regardless of types, size and shape of PW.

Similar results were also reported in fiber-reinforced SCC, where increasing PP decreases the compressive strength Ghanem et al. (2021), due to poor dispersion of fiber. Besides that, the shape of PW could create voids that resulted in poor compressive strength. Zaroudi et al. (2020) demonstrated the compressive strength of SCC increases with PW content up to a certain level and decline with a further increase in PW. The reduction in compressive strength of PW reinforced SCC proved that PW could affect the bond properties and frictional pull-out behaviour (Mastali et al., 2018).

PW is also utilised as in the production of cement mortar and road construction as aggregate. Similar pattern was observed in the compressive strength as a result of mortar from the past studies. High-density polyethylene (HDPE) (Eweed et al., 2018), low-density polyethylene (LDPE) (Ohemeng & Ekololu, 2019) and polypropylene (PP) (Akinyele & Toriola, 2018) were used in the production of mortar. The increasing amount of PW aggregate decreases the compressive strength of mortar. This was mainly to due to the smooth surface of PW aggregate which weaken the adhesion between cement paste at the interfacial transition zone. This may result in high porosity of mortar that reduces the compressive strength.

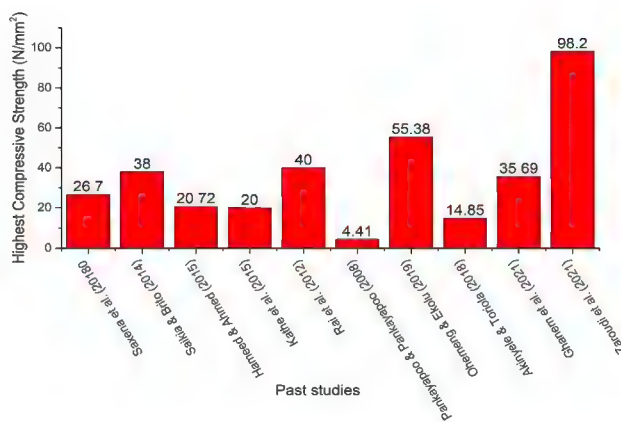


Figure 1. Highest compressive strength of plastic waste included construction based on previous studies.

However, the addition of PW in modified bitumen concrete for road construction showed a positive result (Sarkar & Pal, 2016). The findings proved that robust properties of PW helped to increase the compressive strength in road construction.

In an investigation on utilization of PW in asphalt modifier, Junaid and Jan (2016) used LDPE to produce modified hot mix asphalt (HMA) in various percentages. The findings suggested that increasing amount of LDPE improved the overall strength and performance of HMA. Besides, the LDPE also reduced the tendency of HMA to become soft and less susceptible to temperature change. Similar results were reported by Sultana and Prasad (2012) which evaluated the potential of HDPE, LDPE and PP as a modifier for asphalt concrete and cement concrete pavement. In addition, the asphalt modifier with LDPE aggregate showed higher compressive strength than HDPE and PP aggregate that could be used as a modifier in road construction. Figure 1 shows the highest compressive strength of construction materials from previous studies on construction material.

5.2. Findings on the use of plastic waste in the production of bricks

Bricks have a remarkable history as the main construction and building material. The demand for bricks is expected to be continuously rising due to the substantial increment in new construction projects (The Freedom Group Incorporation Press Release, 2014; Brick Hunter, 2018). Generally, there is two main types of brick used in construction, (a) clay bricks and (b) cement bricks. However, these two types of bricks consumed much energy and raw materials in the production stage, which results in a shortage of the raw materials. Numerous studies have attempted to utilise PW to produce bricks as an alternative option towards the circular economy and environmental protection (Manjarekar et al., 2017; Nursyamsi et al., 2019; Taaffe et al., 2014). PW used in the production of bricks in raw material, aggregate and additive will be discussed in the following sections.

5.2.1. Plastic waste as raw material

5.2.1.1. Water absorption rate. Aiswaria et al. (2018) to produced bricks by incorporating melted PET bottles with manufactured sand (M-sand). The results showed that the water absorption rate decreases as the PET content increases. Similar findings were also recorded when increasing the amount of PET (Hiremath & Shetty, 2014) and PW (Mahajan et al., 2018) could decrease the water absorption rate of the bricks. Besides PET, bricks made of a compact disc (CD) and sand recorded lower water absorption as compared to the conventional bricks (Singh et al., 2017). Thirugnanasambantham et al. (2017) also proved that the water absorption rate of plastic bricks is lower as compared with fly ash bricks. Alighiri et al. (2019) suggested that the low water absorption rate of plastic bricks was due to the low porosity of PET and an increase in the amount of PET. The water absorption rate of plastic bricks is also influenced by the size of aggregate. Misal et al. (2019) demonstrated that the water absorption of bricks with 4.75 mm sand has higher water absorption rate of 5.7% at 1:5 plastic-to-sand ratio as compared with

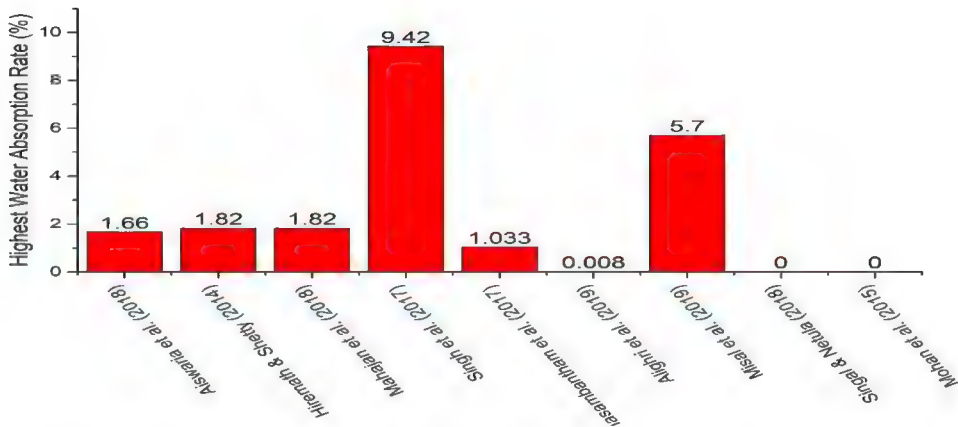


Figure 2. Highest water absorption rate of bricks utilised plastic waste as raw material based on previous studies.

1.8% when bricks produced with 600 μm sand size. Other studies also demonstrated that bricks made up of PW showed no change in terms of water absorption rate (Singhal & Netula, 2018; Mohan et al., 2016). These studies suggested that the hydrophobicity nature of plastic waste could decrease the water absorption rate of plastic bricks. Figure 2 shows the highest water absorption rate of bricks utilised plastic waste as raw material based on previous studies.

5.2.1.2. Compressive strength. Aiswaria et al. (2018) manufactured bricks by incorporating melted PET bottles with manufactured sand (M-sand). The compressive strength increases along with plastics content up to a certain limit and subsequently, it decreases. Hiremath and Shetty (2014) also demonstrated produce brick using PET waste along with laterite quarry waste and bitumen. The study recorded that the compressive strength of brick depends on the percentage of plastic. Similar thoughts were shared by Mahajan et al. (2018) and Alighiri et al. (2019) as the compressive strength of bricks increases as the amount of PW increases. Another study by Singhal and Netula (2018) indicated that bricks produced using melted PW with stone dust recorded the highest compressive strength of 5.6 N/mm². This showed that higher PW content could elevate the compressive strength of the bricks. Mohan et al. (2016) showed that the highest compressive strength (11 N/mm²) was recorded when 70% of PW was used.

Besides PET waste, compact disc (CD) was also utilised to manufacture bricks by Singh et al. (2017). The study suggested that bricks made up of PW have higher compressive strength (10.6 MPa) as compared with the conventional bricks (1.77 MPa) and light-weighted. This is further proved by Thirugnanasambantham et al. (2017) where bricks made up of PE bags can be used as raw material in bricks production replacing clay. The results demonstrated that plastic sand bricks made up of PE bags have the highest compressive strength of 5.56 N/mm² as compared to fly ash bricks (3.38 N/mm²). Following that, Shah et al. (2017) revealed that bricks made up of 100% plastic dust have higher compressive strength as compared to burnt bricks and are lighter in weight. Shiri et al. (2015) also found that bricks made up of LDPE and PP have the highest compressive strength up to 6.30 N/mm² which is higher than the clay bricks (3.63 N/mm²). These studies highlighted that bricks made up of plastics will sustain a higher load and have greater compressive strength than conventional clay bricks.

Besides the amount of PW, the types of PW also assist to determine the compressive of the plastic bricks. Intan and Santosa (2019) proved that bricks with LDPE have less strength as compared with PET due to their molecular weight and intermolecular forces. Another factor which affects the compressive strength of plastic bricks is the size of aggregate. Misal et al. (2019) showed that bricks made up of coarse sand grains of 4.75 mm have higher compressive strength (6.7 N/mm²) as compared with 600 μm sand (6.5 N/mm²). The obtained results are attributed to the finer sand which absorbed more water resulting in insufficient water for hydration that caused reduction in workability and strength (Ling et al., 2020).

On the other hand, studies also reported that the addition of PW to the production of bricks decreases the compressive strength. Daftardar et al. (2017), examined LDPE bead as a raw material in bricks manufacturing using an extruder. The findings evidenced that the compressive strength decrease along with

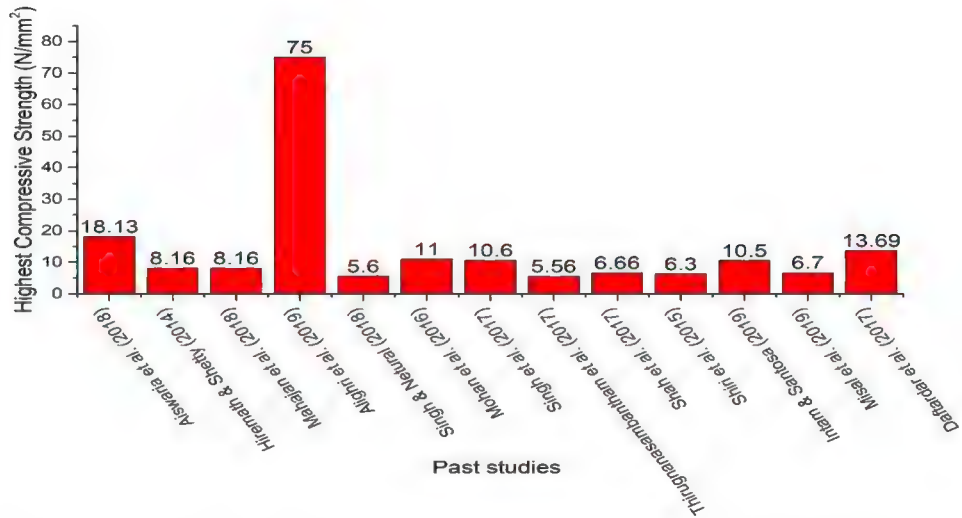


Figure 3. Highest compressive strength of bricks utilised plastic waste as raw material based on previous studies.

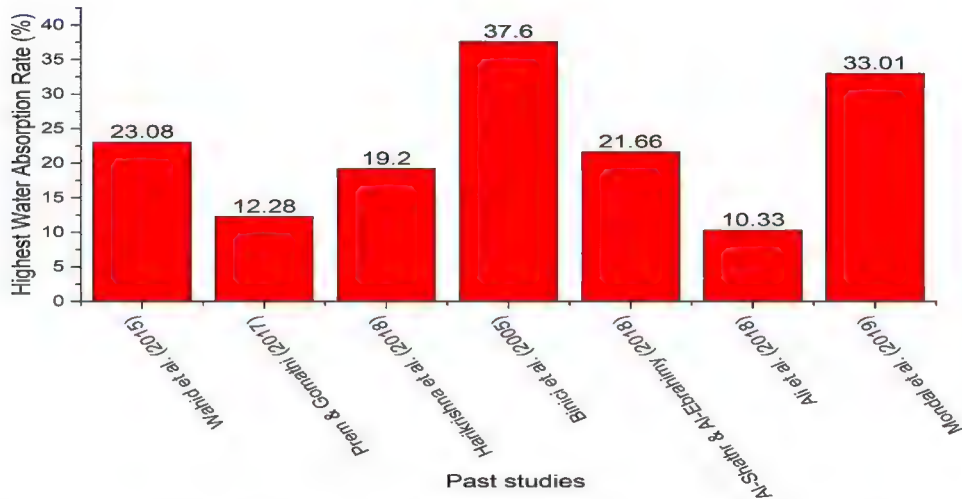


Figure 4. Highest water absorption rate of previous studies on bricks incorporated with plastic waste aggregate.

the amount of LDPE beads despite higher in strength and lower weight as compared with the conventional bricks. Figure 3 shows the highest compressive strength of bricks utilised plastic waste as raw material based on previous studies.

5.2.2. Plastic waste as additive and aggregate

Usage of PW as an aggregate could reduce the needs and demand for natural coarse and fine aggregate (Araghi et al., 2015; Rahmani et al., 2013).

5.2.2.1. Water absorption rate. The water absorption rate of bricks depends on the amount of PW aggregate used. Wahid et al. (2015) observed the water absorption rate decreases as the amount of PET increases. As the PW increases, the porosity decreases due to compaction that resulted in decreased water absorption rate. In contrast, Prem and Gomathi (2017) and Harikrishna et al. (2018) showed the water absorption rate increases along with the amount of PW. The highest water absorption rate of 12.28% (Prem & Gomathi, 2017) and 19.2% (Harikrishna et al., 2018) were recorded when highest

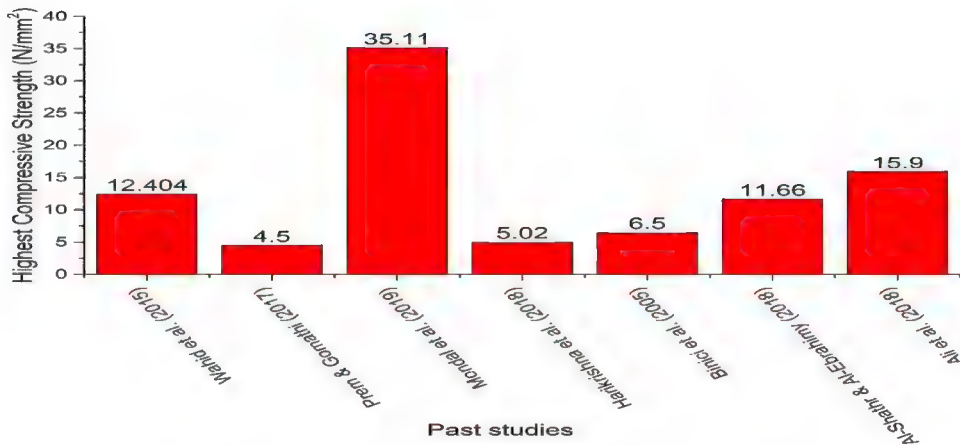


Figure 5. Highest compressive strength of previous studies on brick incorporated with plastic waste aggregate.

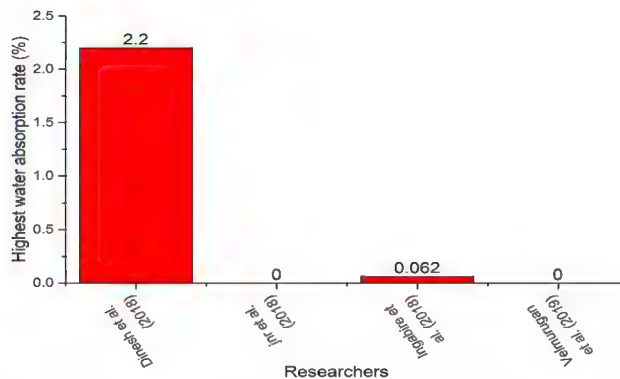


Figure 6. Highest water absorption rate of paving block utilised plastic waste as raw material based on previous studies.

percentage of PW was used. These findings suggested that probably the hydrophobicity and smooth surface of PW have decrease the adhesion force.

Meanwhile, findings also suggest that bricks incorporated with PW aggregate have a similar water absorption rate with conventional bricks. Mud bricks incorporated with PW aggregate have almost similar water absorption rate of 37.6% as compared to conventional bricks (38.7%) (Binici et al., 2005). In another study by Al-Shathr and Al-Ebrahmy (2018), the water absorption rate for the soil bricks with PET aggregate is higher (21.66%) than in the control soil bricks. The rate increases with the amount of waste added due to the voids formed during the firing process which can be filled with water during the curing process. On the other hand, Ali et al. (2018) reported that the HDPE as a sand replacement did not change the water absorption as control sample had higher water absorption rate. Apart from that, different types of PW aggregate also influence the water absorption rate of bricks. Mondal et al. (2019) found that bricks with polycarbonate have higher water absorption rate than polystyrenes and mixed plastics. Figure 4 shows highest water absorption rate of bricks utilised plastic waste as raw material based on previous studies.

5.2.2.2. Compressive strength. Wahid et al. (2015) examined the characteristic of bricks made up of crushed and uniform-sized PET as a replacement for conventional aggregate. The findings showed that the less binding property of plastics decreases the compressive strength as the PET amount increases. Besides PET, the compressive strength of bricks made up of HDPE and PE (Prem & Gomathi, 2017) and mixture of polycarbonate and polystyrene (Mondal et al., 2019) aggregates also decreases as content of

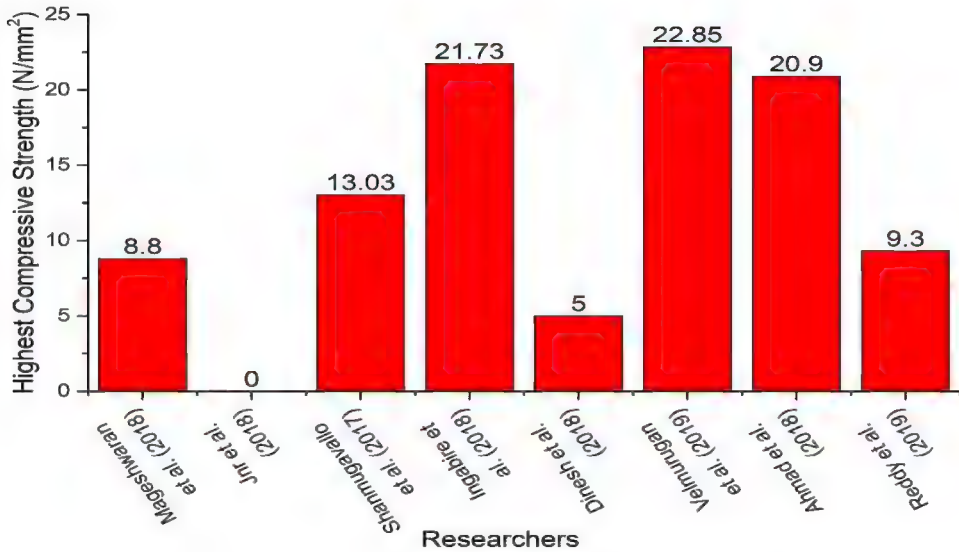


Figure 7. Highest compressive strength of paving block utilised plastic waste as aggregate based on previous studies.

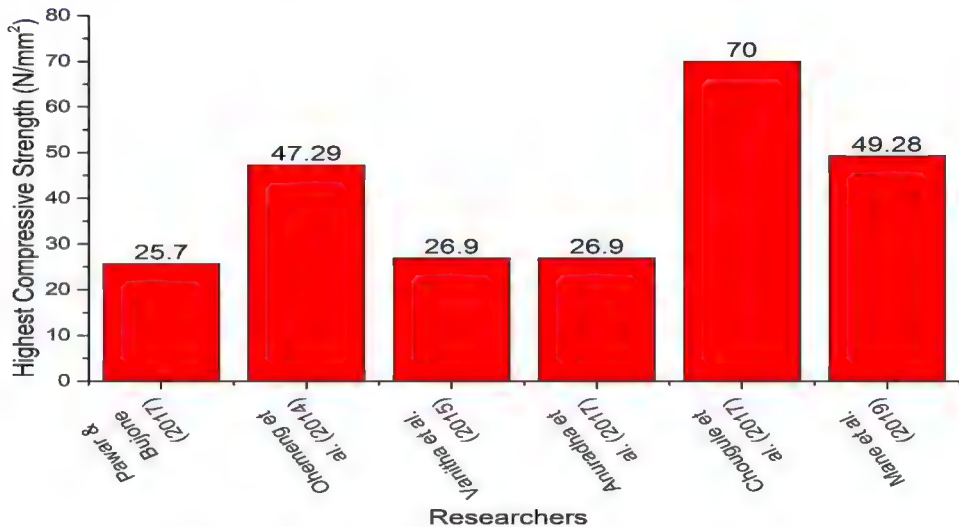


Figure 8. Highest compressive strength of paving block incorporated with plastic waste aggregate.

PW increases. Meanwhile Harikrishna et al. (2018), highlighted that out the compressive strength increases up to a certain percentage of PW and subsequently decreases.

The shape and size of plastic waste also play a role in terms of the compressive strength of bricks. Binici et al. (2005) demonstrated that plastic fibers have better compressive strength of 6.5 N/mm² than plastic straw and polystyrene fabric. In a similar study, Al-Shathr and Al-Ebrahmy (2018) proved that size of plastic aggregate affects the compressive strength of bricks. The highest compressive strength was recorded at 11.66 N/mm² for 1.18 mm PET and 11.03 N/mm² for 2.36 mm PET. The decrease in compressive strength might be due to the presence of voids from the firing process.

Despite the properties of plastic aggregate, the preparation of bricks also influence the compressive strength of the bricks. The unbaked bricks showed higher compressive strength as compared to the bricks baked at 100 °C irrespective to the different types of plastic (Mondal et al., 2019). Another factor which affect the compressive strength of the bricks is the water-cement ratio. Ali et al. (2018) exhibited that bricks with 3% of HDPE using 0.40 water-cement ratio recorded higher compressive strength

Table 1 PESTLE analysis on the utilisation of plastic waste.

PESTLE	Factors
Political (P)	• Government initiatives towards zero PW • The “No plastic bag” campaigns • Banning of the single use plastic materials
Economical (E)	• Aligned with the United Nation’s Sustainable Development Goals (SDGs) • Provide subsidies and incentives • Decrease the demand and cost of conventional raw materials • Circular economy
Social (S)	• Urban-industrial symbiotic relationships • Active participation from all stakeholders • Increase awareness on plastic recycling • Changing consumer’s plastic consumption behaviour • Feasible recycling facilities at the household level
Technological (T)	• Alternative usage and function of PW • Research and development (R&D) on environmentally friendly products
Legal (L)	• Levies on plastic products • Introduce effective environmental laws and regulations
Environmental (E)	• Reduce bioaccumulation of plastic in the environment • Prevent over-exploitation of the natural resources

(15.9 N/mm²) than the control bricks with 0.40 water-cement ratio (14.4 N/mm²). Figure 5 shows highest compressive strength of bricks utilised plastic waste as raw material based on previous studies.

5.3. Studies on the use of plastic waste in the production of paving blocks

Paving blocks or paving bricks are commonly used as the decorative purpose for pavement. Most of the paving blocks can be lifted individually and replaced which allows remedial work to take place. Generally, paving blocks are made of up concrete or clay along with other additives. In recent times, PW is added to paving blocks as raw material, aggregate and additives to reduce PW and enhance durability. Apart from that, PW also serves as an alternative raw material for paving block production.

5.3.1. Plastic waste as raw materials

5.3.1.1. Water absorption rate. Little attention has been given on the water absorption rate in plastic paving block. A study conducted by Dinesh et al. (2018) showed that the highest water absorption rate (2.2%) was recorded as the amount of PW increases. However, some studies reported that the increasing amount of LDPE, decreases the porosity thus decreases the water absorption rate (Jnr et al., 2018). Besides porosity, Ingabire et al. (2018) suggested that the poor water absorption ability of HDPE and compaction of paving block could decrease the water absorption rate. Similarly, an increasing amount of PW causes the paving block to become pulverised which affects the water absorption rate. Apart from that, Velmurugan et al. (2019) found that PE waste included as paving blocks can be used in seashore as PE do not absorb and react with the sea water. Figure 6 shows the summarised previous studies on the water absorption rate of plastic paving block.

5.3.1.2. Compressive strength. Mageshwaran et al. (2018) examined the utilisation of nylon grid, PE bags and M-sand in the production paving block. The results indicated that the compressive strength of the paving block depend on the amount of PW, whereas the compressive strength increases with the amount of PW. Paving block produced using LDPE (Jnr et al., 2018; Shanmugavalli et al., 2017) and HDPE waste (Ingabire et al., 2018) also found that the compressive strength increases as the PW increases. In addition, plastic paving block also found to have higher compressive strength than the conventional bricks. Dinesh et al. (2018) demonstrated that plastic paving block recorded higher compressive strength of 5 N/mm² as compared with the control paver block (1 N/mm²). Similarly, Velmurugan et al. (2019) reported that paving block produced using 30% PE waste and 70% fly ash recorded the highest compressive strength of 22.85 N/mm² as compared to the concrete paving block (17 N/mm²).

On the other hand, increasing PW as raw material in paving block production reported decreasing the compressive strength. Ahmad et al. (2018) showed control paver block with 0% replacement of PET

recorded the highest compressive strength of 21.4 N/mm², followed by 20.9 N/mm², 12.2 N/mm² and 10.9 N/mm² for 5%, 10% and 15% of PET respectively. These findings suggested that lack of adhesion between PET wastes and cement paste could decrease the compressive strength. Similar results were also shared by Reddy et al. (2019) where increasing the amount of PW will cause paving block with pulverised and liquid conditions. Figure 7 shows the summarised previous studies on the compressive strength of plastic paving blocks.

5.3.2. Plastic waste as additive and aggregate

5.3.2.1. Water absorption rate. Increasing the amount of LDPE as PW aggregate reported to influence the water absorption rate of paving block and produced light weighted paving blocks (Ohemeng et al., 2014).

5.3.2.2. Compressive strength. The utilisation of PW as alternate aggregate influences the compressive strength of the paving block. Pawar and Bujone (2017) mentioned that the increasing amount of PE bags aggregate increases the compressive strength up to 25.7 N/mm² at 30% replacement of PE waste. But, in contrast, the compressive strength was found decreasing when with the increasing amount of LDPE (Ohemeng et al., 2014), HDPE (Anuradha et al., 2017; Vanitha et al., 2015) and PP (Chougule et al., 2017) aggregate content due to the reduced adhesion strength. Simultaneously, the study also recorded compressive strength increases as the curing age increases regardless of the amount of plastic used due to the hydration reaction in the cement paste. Apart from that, Mane et al. (2019) showed that the compressive strength of paving block increases with HDPE content up to a certain level and subsequently dropped as the plastic content increases. Figure 8 shows the highest compressive strength of paving block incorporated with PW aggregate in the previous studies.

6. Pestle analysis on plastic waste utilisation

PESTLE analysis is referred to as an analytical tool used to evaluate the impacts of political, economic, social, technological, legal and environmental factors on a study project (Islam & Mamun, 2017; Maliki et al., 2012; Racz et al., 2018; Rastogi & Trivedi, 2016). The PESTLE analysis is also used to evaluate the influence of external surroundings on an issue (Christodoulou & Cullinane, 2019; Srdjevic et al., 2012). Henceforth, the PESTLE analysis is applied in this study to analyse various external factors to ensure the effectiveness of reusing PW in order to solve emerging environmental issues (Fozzer et al., 2017a, 2017b; Sridhar et al., 2016).

6.1. Political perspectives of plastic waste utilization

The political initiatives provided by the governments have a huge impact on the outlook of PW management. For instance, the Ministry of Housing and Local Government (KPKT) in Malaysia reported that about 38000 tonnes of waste were discarded daily where a huge portion from it is plastics (Harun et al., 2019; Kalianan et al., 2020). As a surplus to advocate the efforts of the Solid Waste Management and Public Cleansing Corporation (SWCorps) in Malaysia to resolve increasing PW issue, the Ministry of Science, Technology and Innovation (MOSTI) in Malaysia, formally known as Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC) has introduced the Malaysia's Roadmap Towards Zero Single-Use Plastics 2018-2030 (Ministry of Energy, Science, Technology, Environment and Climate (MESTECC), 2018). This roadmap is aimed to emulate a sustainable natural cycle, where all single-use plastics will be replaced through various phases. Besides, this framework includes all stakeholders such as federal and state governments, manufacturers, suppliers and the general public through the unified and collection approach towards a more sustainable pathway for a cleaner and healthier environment by 2030. The Phase 1 of this roadmap creates an opportunity to embrace and innovate new eco-friendly alternative. As consequences, reusing PW as construction materials could be a positive move towards redesigning products and processes to address plastic pollution.

On the global perspectives, similar initiatives have also be taken in other countries like New Zealand, India, Taiwan, European Union and ASEAN nations to address the PW pollution issue aligned with the

United Nations Sustainable Development Goals (SDGs) where single-use plastics were banned (Godfrey, 2019; Ma et al., 2020; Quoquab & Mohammad, 2020; The ASEAN Post, 2019).

6.2. Economical perspectives of plastic waste utilisation

The political and legal pressures have influenced the economic factors to solve PW issues by providing appropriate subsidies and incentives. However, funding is one of the major obstacles in preparing and implementing programmes and initiatives to tackle the PW problems (Achinas et al., 2019; Sridhar et al., 2016). Reusing PW as a construction material will indirectly boost the Malaysia's economic sectors as a huge amount in about 143.37 billion MYR was spent solely on construction work in 2019 (Hirschmann, 2020). Meanwhile, the cost of raw materials such as cement is expected to be increased in Malaysia in the upcoming years due to the high demand (The Business Times, 2019). As a result, PW could be used as a part of the construction material since it is readily available in enormous quantity yet it provides a new purpose in its life-cycle. Moreover, Cestari (2020), Taaffe et al., 2014, Shiri et al. (2015), Harikrishna et al. (2018), and Pawar and Bujone (2017) highlighted that plastics are robust, durable, waterproof, light-weight and easy to mould are the ideal properties for a construction material. Nevertheless, PW is also available at a more affordable price in comparison with the conventional construction, thus it could reduce the overall production and operational cost.

In addition, the circular economy is an alternative method that aims to keep resources in use as long as possible. The recovered PW is used to the remanufacture new product is widely demonstrated recently, such as bricks, road construction, furniture, and clothes and footwear (Barra et al., 2018). Besides, the circular economy also helps to improve the collaboration between businesses and consumers where it enhanced the public awareness of plastic recycling and increases the value of plastic products. For example, the relevant stakeholders of the urban-industrial symbiosis model in China actively exchange resources between the residential and industrial areas. Through this symbiotic relationship, it managed to reduces up to 78000 tonnes of carbon dioxide emission and 25000 tonnes of PW annually from being dumped into the environment (Sun et al., 2017).

6.3. Social perspectives of plastic waste utilisation

Active participation from all the stakeholders are required to seek appropriate solutions to the globally increasing plastic pollution. Non-governmental organisations (NGOs) and civil societies have to join their hands to increase the awareness on problems related with PW that aligned with the global and regional initiatives such as by European Union's Plastic Strategy in Malta and banning single-use plastic (United Nations Environment Programme (UNEP), 2016). Moreover, many efforts and initiatives were being implemented to reduce the coastal plastic pollution by various organisations such as Clean Blue Lagoon and KwaZulu-Natal (KZN) through beach cleanup activities in the developing countries (Rensburg et al., 2020).

Besides, the willingness of consumers to change their consumption patterns and behaviour is crucial as it has a direct impact on the demand for plastic product. This signifies the importance to understand the consumer's perception in solving problems associated with PW (Lebreton et al., 2017). In spite of that, most Malaysians showed a positive attitude and efforts to reduce the PW leading to the necessity of more recycling system facilities which could assist the plastic recycling process at the household level (Afroz et al., 2017).

6.4. Technological perspectives on plastic waste utilisation

The technological development and innovation in the industry will influence the PW utilisation in the local market. Previously, raw materials such as cement, sand, clay and mud are used as the raw materials for concrete, bricks and paving blocks. However, over-exploitation of these raw materials has resulted in resource depletion (Lawrence et al., 2020; Luangchroenrat et al., 2019). Recently, many studies are conducted on reusing PW as an alternate construction raw materials such as (1) cement, clay and mud where the PW was melted and incorporated with other materials and (2) sand and stone chips where the plastic aggregates are used in the production of bricks, pavers, mortars and concrete. The studies conducted by Ohemeng et al. (2014) Vanitha et al. (2015) and Mane et al. (2019) highlighted that PW can be used as a

replacement for natural aggregate meanwhile, Sarkar and Pal (2016), Saxena et al. (2018) and Hameed and Ahmed (2019) indicated PW could be the raw resource in the production of construction materials.

6.5. Legal perspectives on plastic waste utilisation

The legal perspectives also play an important role in determining the roots and solutions for PW. The compulsory levies on plastic products is an important measure to reduce the production of excessive PW. For example, Denmark was the first country to introduce levies on plastic manufactures, as it reduces the usage of plastic products by 66% (Afroz et al., 2017). Subsequently, other countries such as Mexico, China, Nepal, India and Malaysia also introduced similar taxes and tariffs on PW. Nevertheless, Nyathi and Togo (2020) highlighted that the legislation implementation remains a great challenge in many countries, especially in the African continent due to stakeholder resistance and weak enforcement. Therefore, a feasible and effective enactments must be put in practiced in order to ensure harmonisation in the environmental legislation system (Bhagat et al., 2016).

6.6. Environmental perspectives on plastic waste utilisation

The influence of environmental factor plays an important role in creating awareness of PW pollution. Many studies have been conducted by reusing plastic in construction material to reduce the accumulation of PW in the environment as well as to lower the risk of over-exploitation in natural resources (Al-Shathr & Al-Ebrahimi, 2018; Binici et al., 2005; Hameed & Ahmed 2019; Junaid & Jan, 2016;; Rai et al., 2012). Moreover, PW utilisation in the construction sector is a more favourable and effective option than landfilling and incineration (Awasthi et al., 2017; Schmaltz et al., 2020). Table 1 represents the PESTLE factors affecting the reuse of PW as construction material.

7. Conclusions and recommendations

Reusing PW in construction material has proven to be an alternative method instead of recycling or landfilling to tackle PW pollution. The following conclusions can be drawn based on the critical review on the review utilisation of plastic in various construction material especially bricks and paving block:

- The durable properties of PW enable them to be an ideal material to be used in the construction where the addition of PW enhances the overall strength. However, the smooth and low adhesion property of PW prevents them from binding with other components, thus result in lower compressive strength. Studies also found that PW as aggregate up to certain amount could enhance the compressive strength.
- PW increases the porosity by creating voids due to the low affinity nature of plastics, thus increasing the water absorption rate. There are correlations among the amount of PW added, adhesion force, porosity, water absorption rate and compressive strength. For instance, the high content of PW decreases the adhesion force and creates voids, increasing the porosity and water absorption but decreasing overall compressive strength.
- Both PET and LDPE are the most commonly used PW as raw materials, aggregate and additives in the production of construction materials.
- Most studies only focused solely on the compressive strength and rate of water absorption to evaluate the plastic added construction material's properties. Further studies are required on plastic added construction material considering different parameters such as fire resistance, flexural strength, leaching properties and skid resistance.
- PESTLE analysis indicated that there are many initiatives taken to reduce the bioaccumulation of PW through various methods. Plastic products in many countries are subjected to levies on both manufacturers and consumers through law enactments which have significantly lower down the demand. Apart from that, incentives are also commonly provided to boost plastic recycling.

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